BEHAVIORS OF ASHES IN PRESSURIZED FLUIDIZED BED COMBUSTION OF COAL

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1. Introduction
One of advanced technologies for coal firing power generation is a combined system based on the pressurized fluidized bed combustion (PFBC) because PFBC has been proved to promise high combustion and power generation efficiencies, use of wider range of coals, and efficient environmental protection. The development of PFBC in Japan has been initiated by Electric Power Development Co and three commercial plants have been constructed. Figure 1 illustrates the flow system of PFBC. For flue gas cleaning, cyclone and CTF are installed. In PFBC, coal grains as fuel and CaCO₃ fed as desulfurization agent are fluidized in a bed to perform catalytic combustion and in-situ desulfurization. The combusted gas is sent to the gas turbine after the cleaning to remove fly ash by cyclone and/or high temperature ceramic filter. The combustion heat is recovered in the bed for steam power generation.

The coal is combusted, leaving ash in the bed of CaCO₃ and CaO which is converted into CaO and CaSO₄ by the heat and with SO₂ evolved from the coal combustion. The ratio of CaO/CaCO₃ is influenced by the temperature and CO₂ partial pressure in the bed. Such coal ash and fluidizing agent suffer the collision, adhesion, fusion, and reaction among the minerals in the bed, influencing strongly the performances in PFBC such as efficiency and operability of the ceramic filter, bed fluidization, and desulfurization.

In the present paper, the flue gas cleaning by ceramic tube filter (CTF), fluidization stability of bed materials, and desulfurization efficiency were viewed in terms of coal ash. The interactions among the coal ashes and fluidizing agent govern performances, being strongly influenced by the coal kind, more definitely ash minerals carried by coal. The fluidization stability is very critical for PFBC operation since reactions among the coal ash and CaCO₃/CaO/CaSO₄ may cause the adhesion, agglomeration, and slugging of the bed materials, leading finally to the emergency shut down.

2. Experimental
Ash mineral and bed materials were recovered from ceramic filter and boilers of both 71MW and 350MW demonstration and commercial PFBC plants. Blair Athol, Drayton and Nanton coals were combusted in PFBC plants. Recovered ash and bed materials were observed extensively by high resolution SEM, and analyzed by XRD.

3. Results
1) Ash recovered from ceramic tube filter
Ash minerals recovered from CTF were observed extensively by high resolution SEM to understand two observations (1) why sending lager minerals could improve operability of CTF. (2) combustion of some coals caused large pressure drop through CTF in spite of frequent back wash cleaning. Figure 2 illustrates SEM photographs of ashes which passed through cyclone or some of which by-passed the cyclone to send lager grains of ash. The fly ashes which passed through the cyclone were controlled to fine ones which were packed compact on the filter, increasing the high pressure drop. In contrast, the presence of large grains reduced the packing density of fly ashes on the filter. Hence the pressure drop was moderated and back washing operability was improved even if the more fly ash was sent to CTF. The large ash grain was noted to carry the fine grains adhered to the surface of the large grains as shown in Figure 3. Such adhesion moderates the packing of ashes over the CTF and hence pressure drop.

Figure 4 shows the ash recovered from CTF after the back wash when Drayton coal was combusted. The very fine fly ash was recovered. Such fine ash penetrates into the pore of CTF, being difficult to be removed completely from the filter in spite of the back wash. Such ash causes the increase of stationary pressure drop through CTF. SiO₂ was the major component of the fine ash in the particular coal of Drayton, being not trapped by the large grain because of its low reactivity and high softening point. Thus, behaviors and natures of the very fine ash are very critical for the CTF operation.

2) Sinter grain and agglomerate in the fluidized bed of PFBC
Figure 5 illustrates the photographs of larger grains observed in the bed materials recovered from PFBC boiler. Adhesion and some fusion of fine grains were certainly observed according to the coal kinds as well as the load level of coal.

SEM photographs suggest that the agglomerate consisted of three main parts, dense grains of fine particles fused densely each other, and adhered particles of Al₂O₃, SiO₂, and CaO. Dense grain was identified as SiAlCaO₃ to be formed from the reactive fine particles of SiO₂, Al₂O₃, and CaO. An adhered ash and CaO grain surrounded the dense grain. Such agglomerate appeared to be produced below 1100 °C and disturbs the fluidization, triggering the slugging. The high reactivity of fine ashes and CaO is believed as the major cause of agglomeration.

3) Desulfurization efficiency according to coals to be combusted
Figure 6 summarizes the desulfurization efficiency of PFBC which is definitely influenced by the coal to be combusted in the boiler in addition to Ca/S rate. Nanton coal definitely lowered the desulfurization efficiency. Desulfurization efficiency or SO₂ concentration in flue gas was governed in principle by the reaction of CaCO₃(CaO) and SO₂. However since Ca/S rate was always enough high in the fluidized bed, SO₂ concentration in the flue gas may be determined by the following reactions of CaO – SO₂ – 1/2O₂ and CaSO₄ in the free board and transfer line. Hence, CaSO₄ content and morphology of fly ash are principally concerned to govern the desulfurization extent.

4. Summary
PFBC operation is revealed to be strongly governed by the ash derived from coal. The component and particle size of ash are strongly subjective to the coal, and fine grains among a series of ash minerals appear to strongly influence the operability of PFBC through their reactions and softening temperature. Their adhesion causes the agglomerates and lower the desulfurization, while is favorable at the filtering because fine particle may not penetrate into the pore. Thus, the properties of fine ashes in the coal must be principally concerned. The behaviors and formation mechanism of fine particle ashes must be carefully characterized for the efficient operation of PFBC.

References

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Figure 1. Schematic of PFRC

Figure 2. SEM photographs of CTF ash

Figure 3. High resolution of SEM photographs of CTF ash

Figure 4. SEM photograph of major ash from DT coal penetrated into CTF
Figure 5. Photograph of bed materials recovered from FFBC.

Figure 6. Desulfurization rate as combustible sulfur rate (50% load).